

	L #	Hits	Search Text	DBs	Time Stamp
1	L3	19	((("6337289") or ("20020009861") or ("5046045") or ("5392189") or ("5959702") or ("6001702") or ("2004026621") or ("6797525"))).PN.	US- PGPUB; USPAT; USOCR; EPO; JPO; DERWENT ; IBM_TDB	2005/06/07 18:10
2	L5	8	3 and (aluminum or Al or AlO or "Aluminum oxide" or AlON or "Aluminum oxynitride" or AlN or "Aluminum nitride")	US- PGPUB; USPAT; USOCR; EPO; JPO; DERWENT ; IBM_TDB	2005/06/07 19:21
3	L6	6	5 and (temp or degree or temperature)	US- PGPUB; USPAT; USOCR; EPO; JPO; DERWENT ; IBM_TDB	2005/06/07 18:29
4	L7	4	((("5959327") or ("5046045"))).PN.	US- PGPUB; USPAT; USOCR; EPO; JPO; DERWENT ; IBM_TDB	2005/06/07 18:32

	L #	Hits	Search Text	DBs	Time Stamp
5	L8	2	("5046045").PN.	US- PGPUB; USPAT; USOCR; EPO; JPO; DERWENT ; IBM_TDB	2005/06/07 18:32
6	L9	2	7 and (aluminum or Al or AlO or "Aluminum oxide" or AlON or "Aluminum oxynitride" or AlN or "Aluminum nitride")	US- PGPUB; USPAT; USOCR; EPO; JPO; DERWENT ; IBM_TDB	2005/06/07 18:34
7	L10	853	expos\$6 near4 (Al or Aluminum) near8 (oxygen or nitrogen or N or O)	US- PGPUB; USPAT; EPO; JPO; DERWENT ; IBM_TDB	2005/06/07 19:20
8	L11	624	L10 and temperature	US- PGPUB; USPAT; EPO; JPO; DERWENT ; IBM_TDB	2005/06/07 19:20

	L #	Hits	Search Text	DBs	Time Stamp
9	L12	435	L11 and ((@ad<"20010105") or (@rlad<"20010105"))	US- PGPUB; USPAT; EPO; JPO; DERWENT ; IBM_TDB	2005/06/07 19:20
10	L13	156	L12 and (low near2 temperature)	US- PGPUB; USPAT; EPO; JPO; DERWENT ; IBM_TDB	2005/06/07 19:20
11	L14	156	13 and (aluminum or Al or AlO or "Aluminum oxide" or AlON or "Aluminum oxynitride" or AlN or "Aluminum nitride")	US- PGPUB; USPAT; USOCR; EPO; JPO; DERWENT ; IBM_TDB	2005/06/07 19:21
12	L15	25	14 and capacitor	US- PGPUB; USPAT; USOCR; EPO; JPO; DERWENT ; IBM_TDB	2005/06/07 19:21

US-PAT-NO: 6245606

DOCUMENT-IDENTIFIER: US 6245606 B1

TITLE: Low temperature method for forming a thin,  
uniform layer  
of aluminum oxide

----- KWIC -----

Abstract Text - ABTX (1):

This invention pertains generally to forming thin aluminum oxides at low temperatures, and more particularly to forming uniformly thick, aluminum gate oxides. We disclose a low temperature method for forming a thin, uniform aluminum gate oxide 16 on a silicon surface 12. This method includes providing a partially completed integrated circuit on a semiconductor substrate 10 with a clean, hydrogen terminated or atomically flat, silicon surface 12; forming a uniformly thick aluminum layer 13; and stabilizing the substrate at a first temperature. The method further includes exposing the aluminum layer to an atmosphere 14 including ozone, while maintaining the substrate 10 at the first temperature. In this method, the exposing step creates a uniformly thick, aluminum oxide film 16. This method is suitable for room temperature processing.

Application Filing Date - AD (1):

19991020

TITLE - TI (1):

Low temperature method for forming a thin, uniform layer of aluminum oxide

Brief Summary Text - BSTX (2):

This invention pertains generally to forming aluminum oxide dielectrics at low temperatures, and more particularly to forming aluminum gate oxide layers with high thickness uniformity.

Brief Summary Text - BSTX (7):

Pure SiO<sub>2</sub> gate dielectrics will not be scaleable below 2 nm because of reliability problems (premature breakdown) and high leakage. This lack of scaleability motivates the search for higher dielectric constant materials. Generally, the search has centered on materials with  $\epsilon > 20-50$ , thus providing significant margin. However, we believe that even moderate dielectric constant materials ( $\epsilon = 10$ ) can provide useful gate dielectrics, if a suitable manufacturing method is developed. Al<sub>2</sub>O<sub>3</sub>'s thermodynamic stability on Si and moderate dielectric constant ( $\epsilon = 10$ ) makes it a potential choice for a gate dielectric. We believe this usefulness may exist even though many artisans have avoided aluminum contact with Si, due to the potential of spiking.

Brief Summary Text - BSTX (8):

The current method typically used for forming Al<sub>2</sub>O<sub>3</sub> is sputtering pure Al in an AR/O<sub>2</sub> ambient. This sputter deposition method of Al in an O<sub>2</sub> ambient tends to oxidize the Si substrate at onset of deposition, forming an undesirable SiO<sub>2</sub> layer. It is also difficult to reproducibly deposit .about.30-60 angstroms this way.

Brief Summary Text - BSTX (9):

Sputter deposition, rapid thermal oxidation and furnace annealing are three current methods for forming aluminum oxide gate dielectrics. However, current methods do not reliably produce gate oxides with the thickness uniformity and interface smoothness that will be needed to make devices with approximately 2-4 nm gate oxides practical. Additionally, these methods add significantly to the wafer's thermal budget.

Brief Summary Text - BSTX (10):

We disclose a low temperature method for forming a thin aluminum oxide gate dielectric on a silicon surface, the method includes providing a partially completed integrated circuit on a semiconductor substrate with a

clean silicon surface; determining a first planned temperature--no greater than about 300 degrees C.--for an aluminum oxide film formation; thereby substantially determining a potential thickness of oxidizable aluminum. The method further includes forming a uniformly thick layer of aluminum on the silicon surface to form a temporary aluminum layer, the temporary aluminum layer having a thickness no greater than the potential thickness of oxidizable aluminum; stabilizing the substrate at the first planned temperature; and exposing the temporary aluminum layer to an atmosphere including ozone, while maintaining the substrate at the first planned temperature. In this method, the exposing step creates a first, uniformly thick, aluminum gate oxide film. The method also typically includes forming a gate electrode on the aluminum gate oxide film.

Brief Summary Text - BSTX (11):

In some embodiments, exposing the aluminum layer to an atmosphere including ozone uses a commercial ozone generator, while others include exposing the aluminum layer to an atmosphere including molecular oxygen, while irradiating at least a portion of the atmosphere with an ultraviolet light, where the light transforms some of the oxygen to ozone. In some embodiments, the atmosphere further includes an inert gas, such as argon. Preferably, the ozone at the aluminum layer is not in an excited energy state, such as a plasma. However, a plasma kept away from the wafer may be acceptable.

Brief Summary Text - BSTX (13):

In some embodiments, the first planned temperature is about 25 degrees C. and the aluminum gate oxide film has a thickness of about 10 angstroms. In other embodiments, the first temperature may be up to about 300 degrees C., or even up to 530 degrees C. These temperatures will grow thicker oxides

(up to about 50 angstroms) as shown in FIG. 3.

Brief Summary Text - BSTX (14):

In another aspect of this method, the method further includes depositing a uniformly thick layer of aluminum on the first aluminum oxide film to form a temporary aluminum layer, the temporary aluminum layer having a thickness no greater than the potential thickness of oxidizable aluminum. This potential thickness is found by determining a second planned substrate temperature for a second oxide film formation, the planned temperature no greater than about 300 degrees C.--often the same as the first planned temperature. This planned temperature substantially determines the potential thickness of oxidizable aluminum. After depositing the aluminum, the method further includes exposing the temporary aluminum layer to a second atmosphere containing ozone, while the substrate is at the planned substrate temperature. This exposing step oxidizes the temporary aluminum layer to form a second, uniformly thick, aluminum oxide film extending to the first oxide film; thereby creating a single (combined), uniformly thick, aluminum oxide film.

Brief Summary Text - BSTX (15):

In some embodiments, the method further includes stabilizing the substrate at the second planned substrate temperature before the exposing step.

Drawing Description Text - DRTX (2):

FIGS. 1A-1C show a low temperature method for forming a very thin, uniform aluminum oxide layer.

Drawing Description Text - DRTX (3):

FIGS. 2A-2D show a low temperature method for forming a very thin, uniform aluminum oxide layer.

Drawing Description Text - DRTX (4):

FIG. 3 shows a relationship between time, aluminum oxide thickness, and

oxides with this method. We have found that, if the thermal budget allows, we can easily produce high quality, 4-5 nm thermal oxides at only 500.degree. C. Sometimes an artisan may prefer to use lower temperatures, but grow substantially thicker layers than shown in FIG. 3. For this case, we add extra steps as shown in FIG. 2, but still obtain a highly uniform oxide.

Detailed Description Text - DETX (14):

This variation involves first forming a highly uniform aluminum oxide layer 16 on a silicon surface 12 as described above. Next, another aluminum layer 18 is deposited on the aluminum oxide layer 16. The thickness and uniformity of the final oxide layer will depend upon the thickness of the aluminum layer 18. Thus, like above, aluminum layer 18 should be formed with a well-controlled method, such as sputter deposition or atomic layer epitaxy. This new aluminum surface is then exposed to another ozone/oxygen atmosphere 14, forming a single Al.sub.2 O.sub.3 layer 20. In this step, the total thickness of aluminum oxide layer 20 is determined by the thickness of the aluminum 18 and the underlying aluminum oxide layer 16. However, the ozone allows complete oxidation of much thicker aluminum layers than a straight oxygen atmosphere. If necessary, this aluminum deposition and oxidation can be repeated to form thicker layers.

Detailed Description Text - DETX (15):

FIG. 4 shows a metal-oxide-silicon field-effect transistor (MOSFET) embodiment of this invention. Field-effect transistor 22 has four principal parts: a substrate 24, a source 26, a drain 28, and a gate, where the gate includes the gate electrode 30 and thin aluminum oxide gate dielectric 32. For an NMOS transistor 22, p-type silicon substrate 24 includes n+ source 26 and n+drain 28 regions. Gate dielectric 32 is a very thin, very uniform, aluminum

oxide film, formed by using ozone to oxidize an aluminum layer on clean silicon substrate 24. MOSFET transistor 22 also includes sidewall spacers 34, lightly doped drain (LDD) region 36, and isolation region 38. Those skilled in the art will recognize that these and other features may be used or left out, depending upon the particular function of the device and the intended processing flow.

Detailed Description Text - DETX (16):

These examples have shown NMOS transistors. Since the ozone-based thin aluminum gate oxide method is substantially insensitive to the doping profile of Si, no special modifications are required to implement this invention in PMOS devices or CMOS devices; or into Al.sub.2 O.sub.3 based capacitors, which require a thin, very uniform dielectric with low electrical leakage and a high breakdown voltage.

Detailed Description Text - DETX (17):

Although this method provides substantial benefits when used to form thin oxide layers, it can also offer an improvement over typical methods for forming thicker high-quality oxide layers, such as a dielectric around the floating gate in a flash memory cell. If the thermal budget permits, this ozone-based method can be used to form relatively thick Al.sub.2 O.sub.3 layers in a single pass, or even thicker layers in a layered approach like that described above. Although these thicker layers may require temperatures above 500 degrees C., this variation of the ozone-based method allows lower temperature processing than conventional oxidation processes. Not only do these lower temperatures help the thermal budget, but the self-limiting nature of a ozone-based process improves process repeatability and oxide thickness uniformity, without sacrificing the oxide's electrical quality.

Claims Text - CLTX (1):

1. A low temperature method for forming a thin gate dielectric on a silicon surface, the method comprising:

Claims Text - CLTX (3):

providing a first temperature for an aluminum oxide film formation, the first temperature no greater than about 300 degrees C.; thereby substantially determining a potential thickness of oxidizable aluminum;

Claims Text - CLTX (4):

forming a uniformly thick layer of aluminum on the silicon surface to form a temporary aluminum layer, the temporary aluminum layer having a thickness no greater than the potential thickness of oxidizable aluminum.

Claims Text - CLTX (5):

stabilizing the substrate at the first temperature;

Claims Text - CLTX (6):

exposing the temporary aluminum layer to an atmosphere including ozone, while maintaining the substrate at the first temperature, wherein the exposing step creates a first, uniformly thick, aluminum gate oxide film.

Claims Text - CLTX (7):

2. The method of claim 1, wherein exposing the aluminum layer to an atmosphere including ozone comprises:

Claims Text - CLTX (8):

exposing the aluminum layer to an atmosphere including molecular oxygen, while irradiating at least a portion of the atmosphere with an ultraviolet light, the light operative to transform some of the oxygen to ozone.

Claims Text - CLTX (10):

4. The method of claim 1, wherein exposing the aluminum layer to an atmosphere including ozone includes exposing the aluminum layer to an atmosphere with less energy than a plasma.

Claims Text - CLTX (11):

5. The method of claim 4, wherein at least part of the atmosphere that does not contact the aluminum layer includes an ozone plasma.

Claims Text - CLTX (13):

7. The method of claim 1, further comprising forming a gate electrode on the aluminum gate oxide film.

Claims Text - CLTX (14):

8. The method claim 1, wherein the first temperature is about 25 degrees C. and the aluminum gate oxide film has a thickness of about 10 angstroms.

Claims Text - CLTX (15):

9. The method of claim 1, wherein the first temperature is between 0 and 300 degrees C. and the aluminum gate oxide film has a thickness between 5 and 30 angstroms.

Claims Text - CLTX (16):

10. The method of claim 1, wherein the first temperature is about 300 degrees C.

Claims Text - CLTX (17):

11. The method of claim 1, wherein the first temperature is about 300 degrees C. and the aluminum gate oxide film has a thickness of about 30 angstroms.

Claims Text - CLTX (19):

providing a second temperature for a second aluminum oxide film formation; the second temperature no greater than about 300 degrees C.; thereby substantially determining a second potential thickness of oxidizable aluminum;

Claims Text - CLTX (20):

depositing a uniformly thick layer of aluminum on the first aluminum gate oxide film to form a second temporary aluminum layer, the second temporary aluminum layer having a thickness no greater than the second potential thickness of oxidizable aluminum;

Claims Text - CLTX (21):

exposing the second temporary aluminum layer to a second atmosphere

including ozone, while the substrate is at the second temperature,

Claims Text - CLTX (22):

wherein the exposing step oxidizes the second temporary aluminum layer to form a second, uniformly thick, oxide film extending to the first oxide film; thereby creating a combined, uniformly thick, aluminum gate oxide film.

Claims Text - CLTX (24):

stabilizing the substrate at the second temperature before the exposing step.

Claims Text - CLTX (26):

repeating the depositing, and exposing to an atmosphere including ozone steps at least once; thereby increasing the thickness of the combined aluminum gate oxide film.

Claims Text - CLTX (27):

15. The method of claim 12, wherein the first temperature and the second temperatures are about 25 degrees C. and the combined aluminum gate oxide film has a thickness of about 40 angstroms.

Claims Text - CLTX (28):

16. A low temperature method for forming a thin aluminum gate oxide on a silicon surface, the method comprising:

Claims Text - CLTX (30):

providing a first temperature for an aluminum oxide film formation, the first temperature no greater than about 300 degrees C.; thereby substantially determining a potential thickness of oxidizable aluminum;

Claims Text - CLTX (31):

forming a uniformly thick layer of aluminum on the silicon surface to form a temporary aluminum layer, the temporary aluminum layer having a thickness no greater than the potential thickness of oxidizable aluminum;

Claims Text - CLTX (32):

stabilizing the substrate at the first temperature;

Claims Text - CLTX (33):

exposing the temporary aluminum layer to an atmosphere including ozone,  
while maintaining the substrate at the first temperature, wherein the exposing  
step creates a first, uniformly thick, aluminum gate oxide film; and

Claims Text - CLTX (37):

providing a second temperature for a second oxide film formation,  
the second  
temperature no greater than about 300 degrees C.; thereby  
substantially  
determining a potential thickness of oxidizable silicon;

Claims Text - CLTX (39):

exposing the temporary silicon layer to a second atmosphere  
including ozone,  
while the substrate is at the second temperature,

Claims Text - CLTX (42):

stabilizing the substrate at the second temperature before the  
exposing  
step.

US Reference Patentee Name - URNM (1):

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US Reference Patentee Name - URNM (2):

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US Reference Patentee Name - URNM (4):

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US Reference Group - URGP (1):

3766637 19731000 Norris et al. 438/216

US Reference Group - URGP (2):

4566173 19860100 Gossler et al. 438/216

US Reference Group - URGP (4):

5872031 19990200 Mishra et al. 438/216